PAN-PACIFIC ENTOMOLOGIST
65(4), 1989, pp. 420–428

Biological Control of *Hypera postica* and *Hypera brunneipennis* (Coleoptera: Curculionidae) in California, with Reference to the Introduction of *Tetrastichus incertus* (Hymenoptera: Eulophidae)

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Abstract.—Efforts to achieve biological control of *Hypera postica* (Gyllenhal) and *Hypera brunneipennis* (Boheman) in California, U.S.A., are reviewed. The parasitoid, *Tetrastichus incertus* (Ratzeburg), was recently established and its current distribution is reported. Of the 10 species of parasitic Hymenoptera that have been released into California, only three have been established, a rate of establishment similar to the mean success rate for other biological control programs worldwide.

Alfalfa, a protein-rich perennial forage legume, is grown on more than 450,000 ha in California. Most of this acreage (60%) is concentrated in the Sacramento and San Joaquin valleys, while the rest is scattered throughout the state, in nearly every county and under a great diversity of climatic conditions (University of California Statewide Integrated Pest Management Project, 1985). It is common practice in California for an alfalfa stand to remain in production for 3–4 yr, resulting in a stable and favorable environment ideally suited for a large diversity of arthropods. Dr. E. Schlinger [*in* pers. comm., van den Bosch and Stern (1969)] reported that over 1000 species of insects, mites, spiders, and other arthropods occur in alfalfa grown in California, but of these only six or seven species are known to adversely affect alfalfa yields. The vast majority of the species are neutral or beneficial species. In fact, alfalfa provides a reservoir for many predaceous and parasitic insects that serve as natural enemies for insect pests on a large variety of neighboring crops, maintaining them below damaging population levels (Gonzales and van den Bosch, 1971).

Currently, the most serious insect pest of alfalfa in California is the Alfalfa Weevil, *Hypera postica* (Gyllenhal), and the Egyptian Alfalfa Weevil, *Hypera brunneipennis* (Boheman). *H. postica* is found in the high mountain valleys in the northern and northeastern corner of the state, with the Sierra Nevada and Siskiyou mountain ranges preventing dispersal into the Sacramento Valley; and along the eastern and southern portion of the San Francisco Bay. Michelbacher and Leighly (1940) discussed the spread of the San Francisco Bay population and concluded that dispersal of this population into the San Joaquin and Sacramento valleys was

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limited by high summer temperatures effectively confining it to the San Francisco Bay region.

H. brunneipennis was first recovered in the Yuma Valley, Arizona and adjoining part of California in 1939 (McDuffie, 1941). Apparently not limited by California's high summer temperatures, *H. brunneipennis* gradually spread throughout most of southern California. It was first detected in the San Joaquin Valley near Porterville, Tulare Co. in 1966 (United States Department of Agriculture, 1966) and has now spread northward throughout the San Joaquin and Sacramento valleys of California. The spread and distribution of *H. brunneipennis* throughout California was documented by Madubunyi (1970).

Efforts to achieve biological control of *H. postica* and *H. brunneipennis,* through the importation and colonization of various parasitic hymenoptera, began in 1933 and have continued to date; the history of these efforts in California is reviewed. The most recent species to become established, *Tetrastichus incertus* (Ratzeburg), was surveyed and records of its colonization and current distribution are reported. Finally, the rate of successful introductions is compared with the rate of establishment of natural enemies in other biological control systems.

History of Biological Control

The various species of parasitic Hymenoptera imported and released into California in an attempt to achieve biological control of *H. postica* and *H. brunneipennis* are listed in Table 1. *Bathyplectes curculionis* (Thomson), the first species to be released, was colonized on *H. postica* in the San Francisco Bay region in 1933 (Michelbacher, 1940). It became readily established and spread throughout the region infested by the weevil, causing a substantial reduction in *H. postica* populations (Michelbacher, 1943). In 1941, *B. curculionis* was released at Yuma, Arizona near the Arizona-California border against *H. brunneipennis,* but was not recovered until 1950 when it was found in San Diego County, California, 200 mi west of the original release site (van den Bosch, 1953). Unlike the success achieved on *H. postica* in the San Francisco Bay region, *B. curculionis* had little impact on reducing the population densities and economic damage of *H. brunneipennis* because its eggs were encapsulated by this weevil, rendering the parasitoid ineffective as a controlling agent (van den Bosch and Dietrick, 1959; van den Bosch, 1964).

Prior to 1965, the three populations of weevils (the northern mountains, the San Francisco Bay, and the southern populations) were all isolated geographically. Following the 1966 invasion and subsequent spread of *H. brunneipennis* throughout the San Joaquin and Sacramento valleys, effective biological control in the San Francisco Bay region broke down due to the displacement of *H. postica* by *H. brunneipennis* (van den Bosch, 1972). No *B. curculionis* were released on *H. postica* in the northern mountain valleys at this time.

The material colonized on *H. postica* and *H. brunneipennis* was obtained from Utah where *B. curculionis* had been established in 1911–1913. The sources for this introduction were various locations in southern and central Europe, but the greatest number of parasites apparently come from Germany and Switzerland (Donald Davis, Utah State University, pers. comm.). Failure of the Utah ecotype to control *H. brunneipennis* was thought to be due to its poor adaptation to its host. As a result, a series of surveys were conducted from 1953 to 1984 in several

Table 1. Species of parasitic Hymenoptera introduced into California to control *H. brunneipennis*. This list was updated from van den Bosch (1972).

Host stage affected	Parasite	Family	Status
Egg	*Patasson* sp.	Mymaridae	not established
	Peridesmia discus (Walker)	Pteromalidae	not established
Larva	*Bathyplectes curculionis* (Thomson)	Ichneumonidae	widely established
	B. anurus (Thomson)	Ichneumonidae	recently recovered
	B. stenostigma (Thomson)	Ichneumonidae	not established
	Tetrastichus incertus (Ratzeburg)	Eulophidae	established central CA
Pupa	*Dibrachoides druso* (Walker)	Pteromalidae	established southern CA
	Habrocytus sp.	Pteromalidae	not established
Adult	*Microctonus aethiopoides* (Nees)	Braconidae	recently recovered
	M. colesi Drea	Braconidae	not established

countries of the Near East, including Egypt, Iran, Iraq, and Turkey, in the hope of finding more effective parasitoid species or a race of *B. curculionis* better adapted to *H. brunneipennis* (Clancy, 1969; R. van den Bosch, pers. records). Several introductions of *B. curculionis* were released throughout California, but control of *H. brunneipennis* in the Sacramento, San Joaquin, and Imperial valleys was not successful. However, in the early 1970's, a strain of *B. curculionis* collected in the Near East (probably Iran) was colonized in the high mountain valleys of Siskiyou County, in northern California and has effectively controlled *H. postica* populations in this area (Roger Benton, Agric. Exten., Yreka, pers. comm.). This result suggests that *H. brunneipennis* has not spread into the mountain valleys of northern California.

The various introductions of *B. curculionis* into California have been reviewed by Clancy (1969), van den Bosch (1972), and Hagen et al. (1976). Currently, *B. curculionis* is found throughout the state coexistent with its host (Jordan, 1975).

During the period from 1953 to 1984, nine other species of parasitic Hymenoptera were imported and released into California (Table 1), but of these only *Dibrachoides druso* (Walker) and *Tetrastichus incertus* became established. *D. druso* was established in southern California (Imperial and San Diego counties) on *H. brunneipennis* from releases made in 1960–1962 but was not particularly effective in reducing weevil numbers (Gonzalez et al., 1969). While collected in San Diego County in 1968, 6 yr after releases had ceased (van den Bosch, 1972), it has not been recorded elsewhere in the state to date and its current status in southern California is not known.

The first shipment of *T. incertus* into California occurred in 1935 and 1936 (Peck, 1963). Unfortunately, the fate of this material is not known but there is no record of *T. incertus* being collected in California prior to 1960 (Hagen et al., 1976). *T. incertus* was established in the United States for the first time in 1961 in New Jersey and Pennsylvania by USDA personnel from Moorestown, New Jersey. The material released was derived from a single mummy collected at Roche-fort-du-Gard, France, June 17, 1960 (Streams and Fuester, 1967). Because of its success, four consignments of *T. incertus* totaling 2591 adults and 100 mummies, were shipped from the USDA Moorestown Laboratory to the Uni-

versity of California Quarantine facilities at Riverside and Albany, California in 1963. Various releases propagated from this material were made in Monterey, Riverside, San Diego, and Siskiyou counties from 1963 through 1965 (Table 2). In spite of the numbers liberated, *T. incertus* was not recovered in subsequent surveys (R. van den Bosch, unpubl. Annual Reports, Division of Biological Control, University of California, 1964, 1965).

In 1965, another shipment from Moorestown arrived at Albany, California, and this material was combined with the existing insectary colonies. Releases of this material were made in Alameda, Glenn, Monterey, Riverside, San Diego, Stanislaus, and Tulare counties from 1966 to 1969 (Table 2). Details of the methods used in the propagation and release of *T. incertus* during this period may be found in Clancy (1969). Follow-up surveys in the release areas resulted in very few recoveries the first year and none in the second year.

Failure to colonize the Moorestown strain was thought due to it being poorly adapted to the climatic conditions in California (van den Bosch, 1972). As noted earlier, surveys for parasites of *H. brunneipennis* in several countries in the Near East were made from 1953 through 1984. Collections of *T. incertus* in the Near East were made by Dr. R. van den Bosch during 1968, 1970, and 1973, and by Dr. D. Gonzales, University of California, Riverside, during 1974 and 1984 (unpubl. Quarantine Records, UC Berkeley 1965–1985). It was hoped that these ecotypes would be better suited to California conditions.

Six adults of *T. incertus* from Iran arrived in 1968 and a substantial colony was propagated. Releases from this material occurred in 23 counties throughout the state in 1969 and 1970 (Table 2). In 1970, 190 adults were received from Iran which were combined with the colonies derived from the material received in 1968. In 1973 only six adults (five females and one male) were received from Iran and combined with the existing laboratory colonies. The new material hopefully broadened the genetic base of the insectary stock (unpubl. Quarantine Records, UC Berkeley, 1968–1973). It is not known from how many areas in Iran this material was collected, hence material released during the years 1969–1972 will be collectively referred to as the Iranian I strain.

The greatest number of *T. incertus* were released during 1969–1972 (Table 2). Yet, despite this aggressive colonization and release campaign, *T. incertus* failed to become established (van den Bosch, 1972; Hagen et al., 1976). In 1974, Dr. D. Gonzales travelled to Turkey to search for more natural enemies of *H. brunneipennis,* but unfortunately, all of the *T. incertus* material he sent was dead on arrival (unpubl. Quarantine Records, UC Berkeley, 1974).

On August 7, 1974 a shipment of *T. incertus* was sent by Dr. M. Esmaili of the College of Agriculture, Karaadj University, Iran. This material had been collected from alfalfa fields located on the University grounds. Approximately 350 mummies were received in quarantine and held for emergence. Of the parasitoids that emerged a total of six females were released from quarantine and used to establish a colony in the insectary (L. Etzel, pers. comm.; unpubl. Quarantine Records, UC Berkeley, 1974) hereafter referred to as the Iranian II strain. Releases of this strain occurred in Colusa County in northern California in 1975 and near Kerman, Fresno County, in the heart of the San Joaquin Valley in 1976 (Table 2). The following year, surveys around Kerman picked up *H. brunneipennis* larvae infested with *T. incertus*; surveys during 1978 and 1979 showed that *T. incertus* was

Table 2. Number of *Tetrastichus incertus* released by county in California from 1963 to 1985.

	Moorestown strain						Iranian I strain			
County	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Alameda						200	453	5974		
Butte								3109	8700	
Colusa								12,743		
Contra Costa								1744	25	
Fresno								3345	11,000	
Glenn					51			469		
Kern									9500	
Lassen								10,425	1100	
Madera								635	8600	
Modoc								2504		
Monterey	360							32,512	633	
Placer									1800	
Plumas										
Riverside		1968	2695	5575	3730					
Sacramento									3900	
San Diego		408	550	12,000					24,000	
San Joaquin									10,300	
Shasta								2077		47
Sierra								4256		
Siskiyou	1709							23,886		
Stanislaus				561					6500	
Sutter									3000	
Tehama										
Tulare				70					8000	
Yolo								9190	7300	228

becoming more common in Fresno County and was expanding its range. Further releases from insectary Iranian II stocks occurred in Monterey and Colusa counties in 1980 and 1981; field-collected adults from the Kerman area were released in Monterey County in 1980. No other introductions of *T. incertus* occurred during 1982–1985 (unpubl. Annual Reports, Division of Biological Control, University of California, 1982–1985; K. Hagen, pers. comm.).

Current Distribution of *T. incertus*

Materials and methods.—During 1982 and 1983, a survey of the principal alfalfa growing areas throughout the state of California to determine the current distribution of *T. incertus* was performed. Whenever possible, fields were chosen with hay approximately 0.5 m high. In each field 200–600 sweeps with a standard sweep net were taken. All *T. incertus* adults and all *H. brunneipennis* larvae found were removed and counted. *H. brunneipennis* larvae were placed in containers on alfalfa bouquets and reared for the emergence of parasitoid adults. Survey of the counties north of Yolo County in northern California took place August 25–27, 1982; survey of counties in southern California (Imperial and Riverside counties) took place August 11–12, 1983; surveys of central California (including Yolo County) were made from July 28, 1983 through September 15, 1983.

In addition to this survey, a second independent survey was made by USDA/

Table 2. Extended.

Iranian II strain												
1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
		150						20				
			200									
							50	20				

APHIS during 1982 and 1983. The results of that survey are included (data courtesy of Mr. Milt Holmes, USDA/APHIS, Niles, Michigan).

Results and discussion.—The current distribution of *T. incertus* is shown in Figure 1. It appears that *T. incertus* is now well established in Central Valley of California and in the coastal valleys of Monterey and San Benito counties. In addition, it appears to have dispersed over the Sierra Nevada Mountains into the Owens Valley in Inyo County. *T. incertus* was not collected in Kern County by USDA personnel, but they did report finding a single mummy of *T. incertus* south of there in the north Los Angeles–Santa Barbara County area. No weevil larvae or *T. incertus* adults were collected in the desert regions of Imperial and Riverside counties during the August 1983 survey. Northward, *T. incertus* has extended its range as far as Solono County north of the Sacramento River, but as of Fall 1983, no parasitoids had been recovered in Yolo County a few miles to the north.

It is interesting that some *T. incertus* individuals of the Iranian II strain established in Fresno County were also released in 1975 and in 1980 in Colusa County in northern California. The failure of colonization suggests that this strain of *T. incertus* may be restricted in its expansion into northern California.

Failure of the early colonization attempts of *T. incertus* was attributed to using inappropriate or poorly adapted ecotypes. Certainly, this must have been an important factor. However, poor understanding of the phenology of *T. incertus*

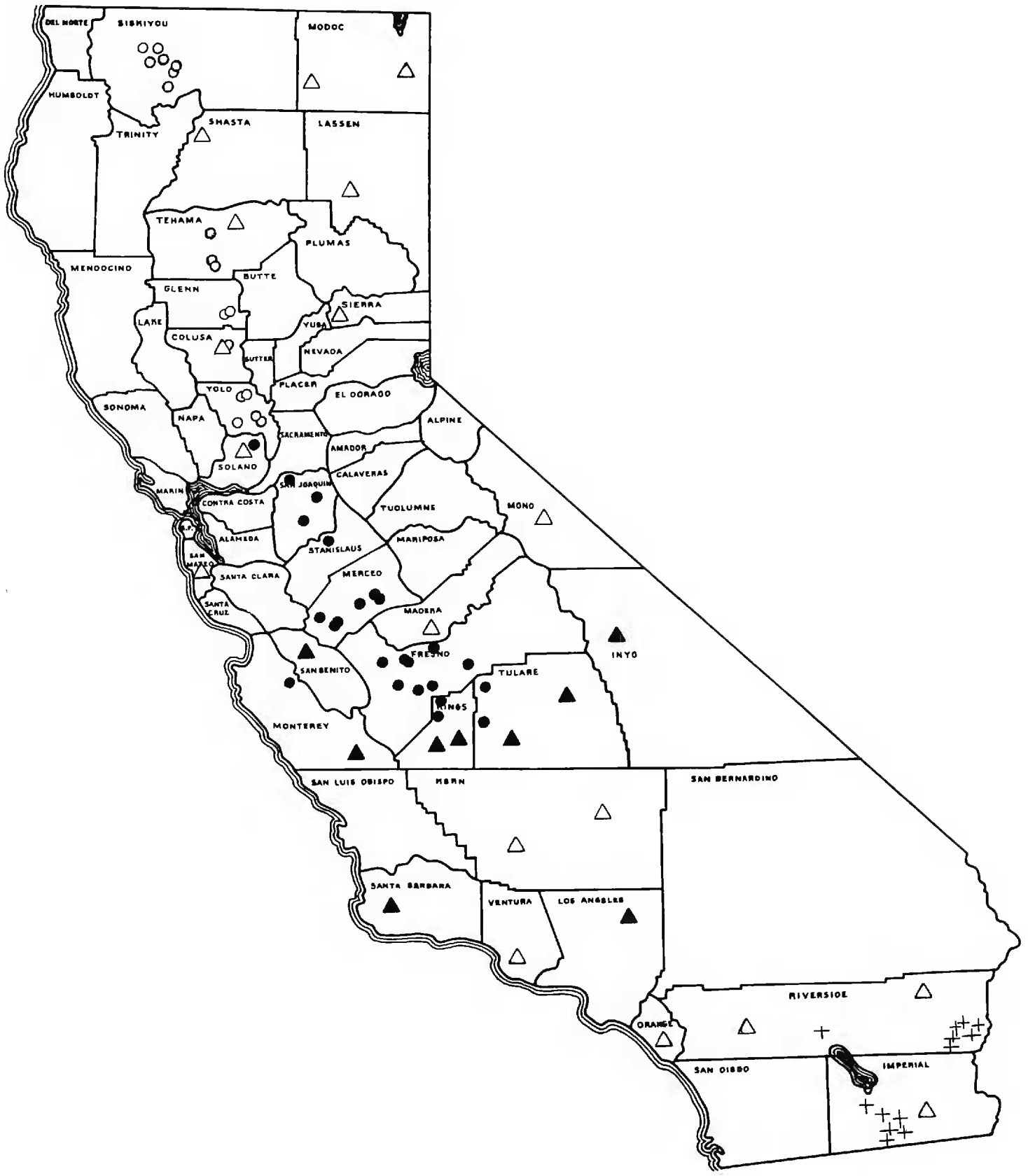

Figure 1. Map of California showing the survey sites for *Tetrastichus incertus* during June through September in 1982–1983. Open symbols (○ or △) represent fields where *Hypera postica* or *H. brunneipennis* were collected but no *T. incertus* were recovered. Closed symbols (● or ▲) represent fields where both *H. postica* or *H. brunneipennis* and *T. incertus* were recovered. The plus symbol represents fields where no *H. postica* or *H. brunneipennis* or *T. incertus* were recovered. The triangles indicate areas sampled by USDA/APHIS (data courtesy of Milt Holmes, USDA, Niles, Michigan).

may have also contributed to the problem. This parasitoid is a summer active insect in California, emerging from diapause in late March and remaining active (given sufficient host material) until the onset of cold weather in the Fall. *H. brunneipennis* usually has one major larval peak each year during February and March, at least 1 mo before *T. incertus* becomes active in the spring. However, a partial second generation of *H. brunneipennis* may occur in California (Pitcairn, 1986) which results in a small but consistent population of larval host activity during the summer. It is on these larvae that *T. incertus* subsists. The releases of *T. incertus* during the 1960's and early 1970's, usually occurred during February and March when *H. brunneipennis* larvae were most abundant, but before *T. incertus* is usually active, while later releases occurred during April and May which improved the chances for colonization. The release of the Iranian II strain in Fresno and Colusa counties occurred during June; a time more consistent with its current phenology in the field (Pitcairn, 1986). *T. incertus* was the most heavily colonized of the *H. brunneipennis* parasites during the period of 1967–1972. Liberations of the other species never totaled more than 25% of *T. incertus* numbers (van den Bosch, 1972). The main reason was that it proved to be a good laboratory species, had a high fecundity, was gregarious, and was easily propagated. Because of its seasonal phenology and small impact on host populations, *T. incertus* has had little effect in reducing *H. brunneipennis* damage in California (Pitcairn, 1986).

An important question is why have only three of the 10 species of parasitic Hymenoptera become successfully established against *H. brunneipennis*. Failure has been attributed to insufficient numbers, poorly adapted climatic strains, lack of alternate hosts, and insufficient funding to increase colonization number, foreign exploration, and biological studies (van den Bosch, 1972; Hagen et al., 1976). Interestingly, the rate of establishment (30%) is very similar to the overall rate of establishment (34%) among biological control efforts worldwide, as reported by Hall and Ehler (1979), but higher than the average rate (22%) estimated for biological control projects in California. However, recent efforts by Drs. K. Hagen and L. Etzel have resulted in the colonization of *Microctonus aethiopoides* (Nees) and *Bathyplectes anurus* (Thomson) in Colusa and Fresno counties. It is too early to tell if these species will become permanently established, but recoveries of both during 1986 and 1987 are very encouraging (Dr. Hagen, pers. comm.). Both of these species were instrumental in achieving successful biological control of *H. postica* in the northeastern United States (Day, 1981) and it is hopeful that the appropriate ecotypes of these species will achieve the same level of success in California.

Acknowledgments

We are grateful to Milt Holmes (USDA/APHIS) for providing the *T. incertus* survey data acquired by USDA personnel. We also thank Lowell Etzel and Ken Hagen for numerous discussions on the topic and Les Ehler for reviewing this manuscript.

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